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(54) Abstract Title  
Electricity generation using fuel cells in jet engines

(57) An aircraft jet engine has a fuel cell 33 integrated within the engine to generate electricity. In a first embodiment, the fuel cell is formed by positioning tiles of a solid electrolytic membrane in contact with the combustion products 386 where they can exploit oxygen partial pressures within the thermodynamic cycle. The surfaces 332,334 of the membrane are coated with a porous metallic conductor such as platinum. Further embodiments have a catalytic reformer to decompose aviation fuel. The reformer may be in the combustion chamber wall (44, fig 4) or outside the combustion chamber (508, fig 5) in the fuel cell (514, fig 5) and fed with high pressure air bled from a compressor (502, fig 5) and also fed with hot exhaust gas via duct (538, fig 5). The hydrogen-rich products contact fuel cells to chemically remove oxygen. The products are combusted and further energy recovered in the engine. A static inverter (516, fig 5) is used to convert the DC current output of the fuel cells into a conventional aircraft AC supply.

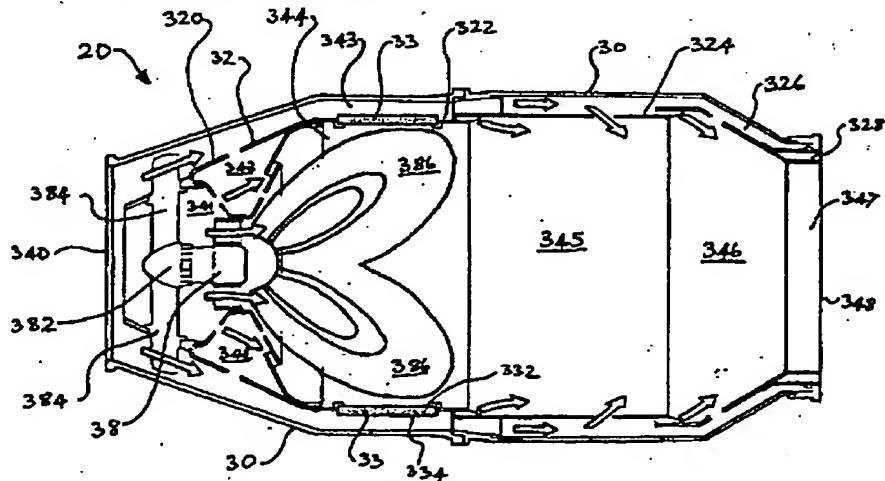
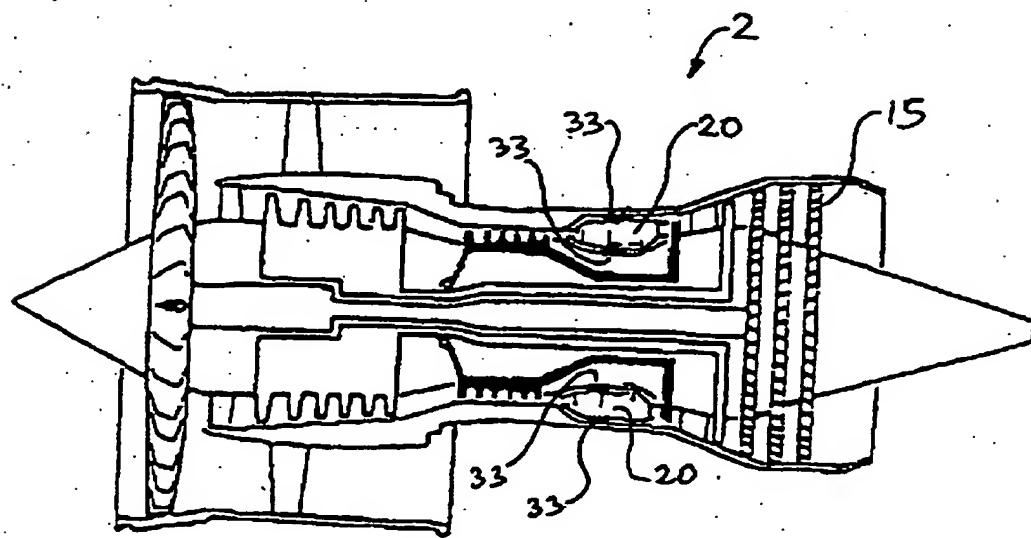
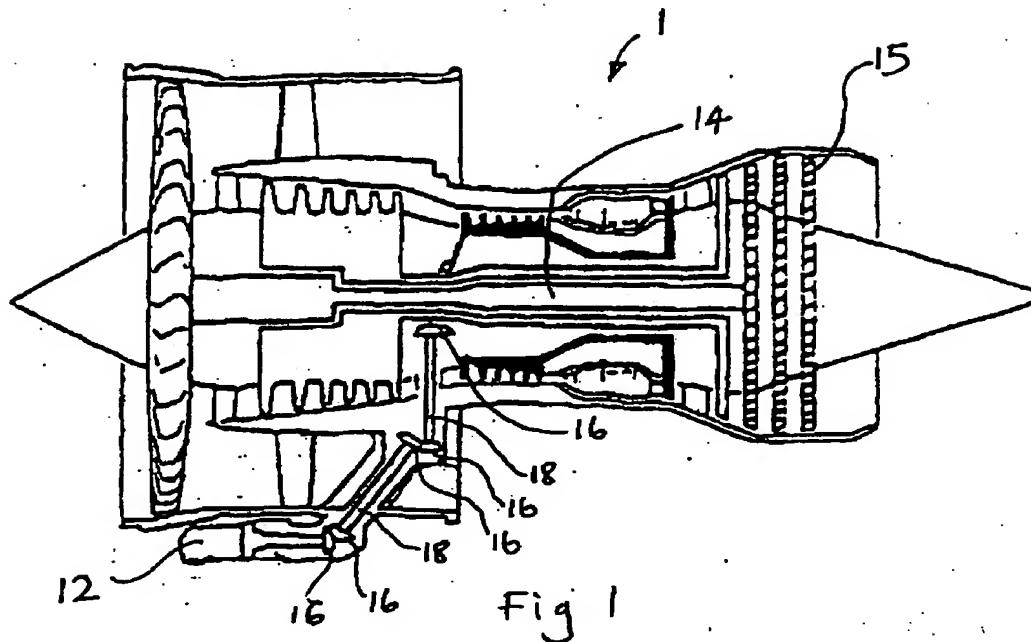


Figure 3

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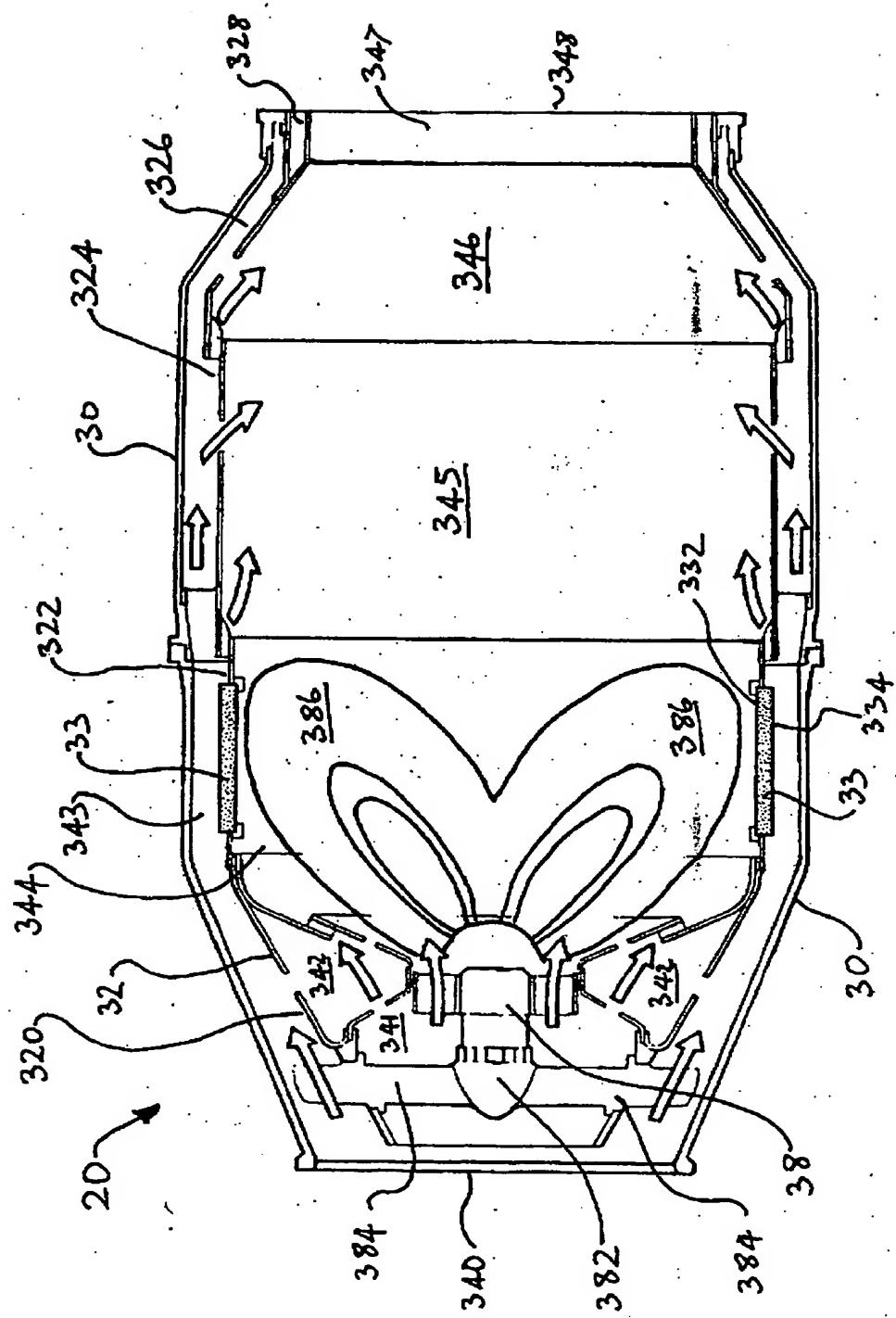


Figure 3

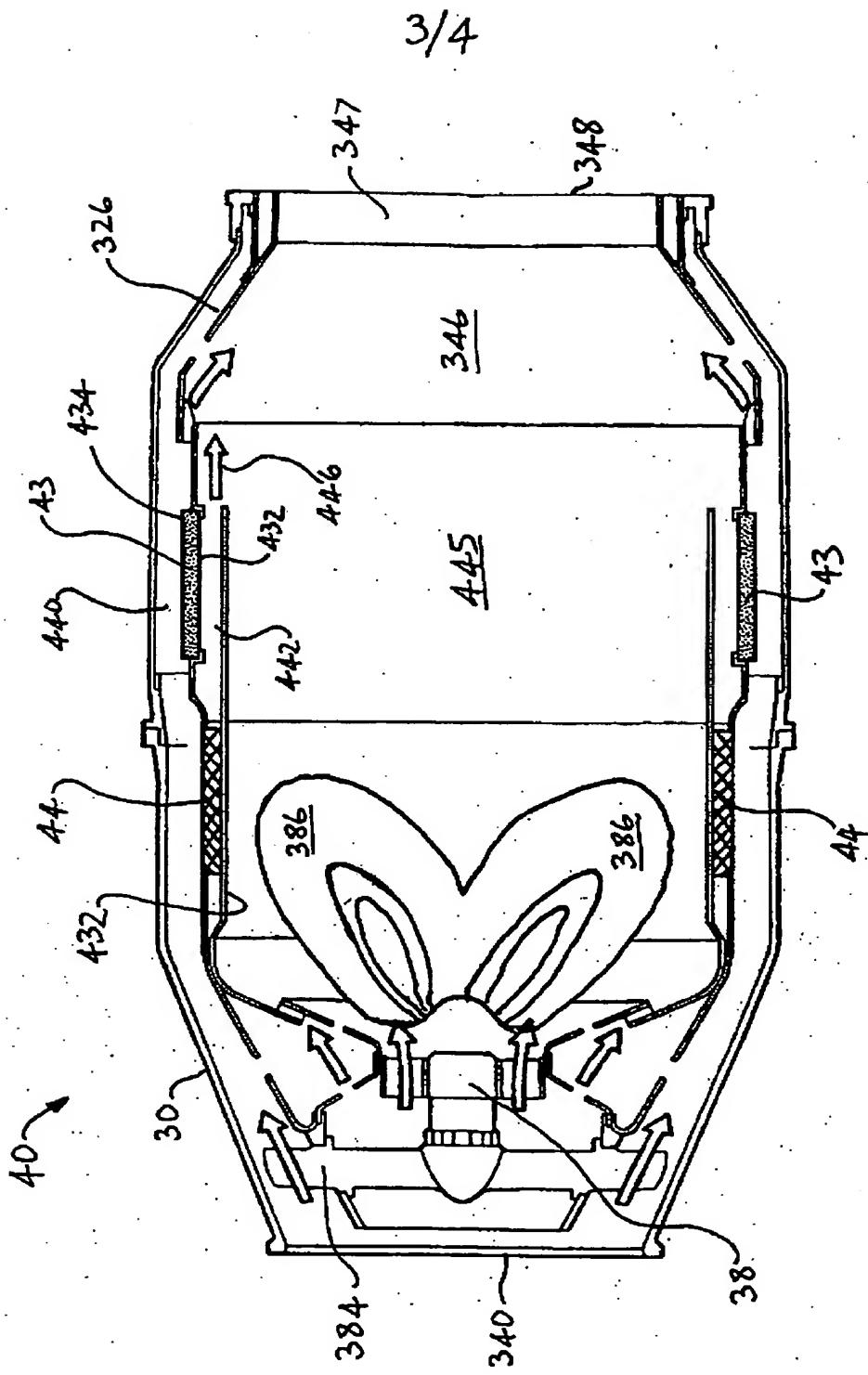


Figure 4

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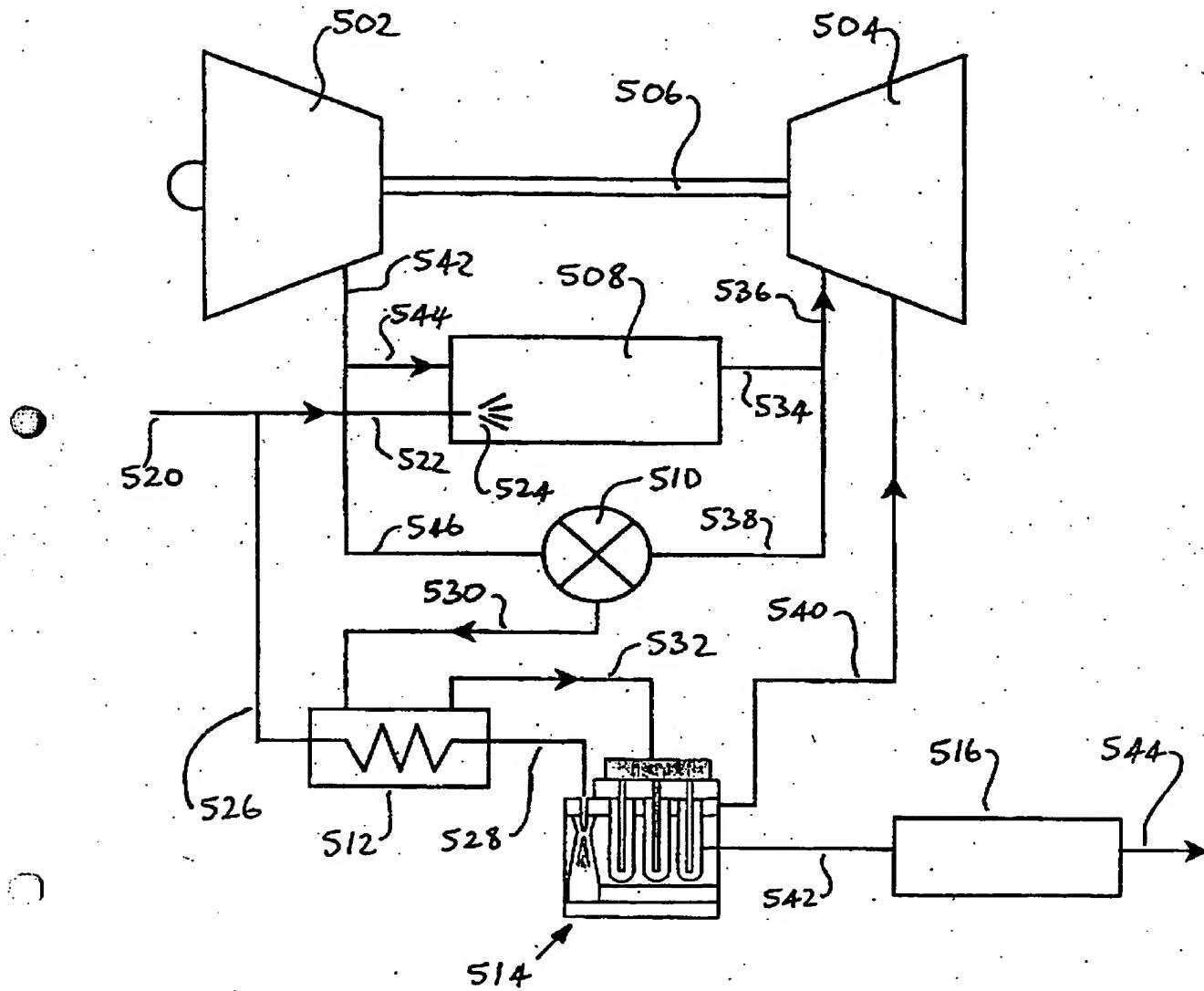


Figure 5

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Jet Engine with Integral Fuel Cell

This invention relates to fuel cells, in particular, fuel cells used in conjunction with jet engines.

5

The current method of generation of electrical power for airborne applications is based on electro magnetic generators driven from the aircraft engine by means of a power off-take shaft and gear box.

10 Such an arrangement is shown schematically in fig 1 in which a jet engine shown generally by 1 incorporates an electricity generator 12 which is mechanically driven from the turbine shaft 14 of the engine via gears 16 and line shafting 18, the turbine blades 15 being rotated by hot gases in the conventional way.

15 While such prior art arrangements are widely used, the mechanical power train requires a number of relatively expensive precision mechanical rotating components.

The present invention seeks to provide an improved way of obtaining electrical power from aircraft engines.

20

The present invention provides a jet engine including an integral fuel cell.

Embodiments of the invention will now be described, by way of non-limiting example

only, with reference to the drawings in which:

Figure 1 shows a sectioned view of a prior art jet engine;

5 Figure 2 shows a sectioned view of a first embodiment of the invention;

Figure 3 shows a sectioned view of part of fig 2 on an enlarged scale;

10 Figure 4 shows a sectioned view of a modification of fig 3 illustrating a second embodiment of the invention; and

Figure 5 shows in schematic form a third embodiment of the invention.

A first embodiment of the invention will now be described with reference to figures 2 and  
15 3. As can be seen in fig 2, a jet engine 2 generates electricity, not by a rotating electrical generator, but by fuel cells 33 disposed within its combustion chambers 20. This completely eliminates moving parts from the electricity generation process and allows the components associated with electricity generation to be disposed within the housing of the engine.

20

Figure 3 shows a sectioned view of one of the combustion chambers 20. Each combustion chamber 20 consists of an outer housing 30 having an inner generally coaxial housing 32 consisting of an inlet portion 320 of generally frusto-conical form, a first

combustion portion 322 in which combustion takes place, a second combustion portion 324 in which combustion products are mixed with air to cool and dilute same, and an outlet portion 326 of generally frusto-conical form leading to generally cylindrical outlet port 328. A combustion nozzle 38 is supported by struts 384 and is supplied with fuel by 5 fuel lines which have been omitted for clarity. A number of fuel cell tiles 33 are arranged in the wall 322 of the combustion chamber.

Each tile consists of a solid electrolyte membrane having a first inward-facing surface 332 in contact with the combustion products of flames 386 produced by the burning of 10 fuel supplied to the fuel jets 38, and a second outward-facing surface 334 in contact with air which flows through the annular space defined between the outer and inner housings 30, 32. The surfaces of the membranes are coated with a porous metallic conductor which in the present embodiment is platinum.

15 The hot gas in contact with the inner surface 332 has a lower concentration of oxygen than the air in contact with the outer surface 334. Ionic conduction of oxygen is driven by the difference in partial pressure of oxygen across the membrane. The metallic coatings provide the electrical connections for the output of the fuel cell. These connections have been omitted for clarity.

20

In this embodiment the membranes are placed at the position of the highest absolute pressure within the engine thermodynamic cycle. This maximises the difference in partial pressure of oxygen and hence maximises the power available from each membrane. Both

the elevated temperatures necessary for the mobility of ions within the electrolyte and the partial pressure to drive the ions through the electrolyte are present at both high and low power settings of the engine.

5 A second embodiment will now be described with reference to figure 4. Figure 4 shows a burner 40 which is a modification of fig 3 and which can be substituted for burners 20 of fig 2. Items which are identical in function with corresponding items of fig 3 have been given identical reference numerals.

10 This arrangement shown in fig 4 includes reformers 44 within the walls of the liner 432 of the combustion chamber. Each reformer 44 consists of a matrix of a catalyst and is fed with hydrocarbon aviation fuel by fuel ducts which have been omitted for clarity. The reformers 44 are maintained at an elevated temperature by the primary combustion flames 386. The high temperature causes the catalyst to decompose the fuel into a hydrogen-rich mixture of gases. This hydrogen-rich mixture passes into chamber 442 where it comes 15 into contact with the respective inner surfaces 432 of fuel cell tiles 43 whose respective outer surfaces 434 are in contact with air in outer chamber 440.

Whereas in the previously-described embodiment, power is limited by the rate at which 20 oxygen molecules can diffuse from the inner surface 332 of the membrane, in the present embodiment, oxygen is chemically removed from inner surface 432 by the hydrogen molecules of the hydrogen rich gas, the hydrogen molecules combining with oxygen to form water. Unused hydrogen and the other hydrocarbon products are burned where they

enter the second chamber 445 at 446. The energy released by this secondary combustion is subsequently recovered in the main engine turbine 15.

A third embodiment will now be described with reference to fig 5. In this embodiment 5 a fuel cell and a reformer are located adjacent to, but externally of, the combustion chamber.

A compressor, shown schematically by 502, is driven by a turbine 504 via a shaft 506. Compressed air from the compressor 502 is fed via ducts 542 and 544 to a combustion 10 chamber shown schematically as 508. Aviation hydrocarbon fuel from a fuel supply 520 is fed via duct 522 to a burner 524 within the combustion chamber. Exhaust gases from the combustion chamber pass via ducts 534, 536 to the turbine 504.

A proportion of the compressed air flows from duct 542 via duct 546 to a first input of 15 a temperature control valve 510. Hot exhaust gas is supplied to a second input of valve 510 via ducts 534 and 538. Fuel pre-heater 512 is supplied with fuel from fuel source 520 via fuel line 526 and with hot gas at a controlled temperature via duct 530. The temperature-controlled gas flows via line 532 to a fuel cell shown schematically by 514. Fuel from the preheater flows into a reformer within the fuel cell package 514 to create 20 a hydrogen-rich supply of gas for the fuel cell. The fuel cell utilises this supply of gas and the oxygen-carrying temperature-controlled air to generate electricity in the manner previously described in connection with the previous embodiments. Gas leaving the fuel cell package passes via duct 540 to turbine 504. The fuel cell and reformer are of

conventional type and will not be described further.

Temperature control valve 510 adjusts the proportions of air from duct 546 and exhaust gas from duct 538 so as to deliver hot gas on duct 532 at the temperature required by the  
5 fuel cell. The fuel cell delivers DC output current on line 542 to a power conditioning circuit 526. Power is delivered therefrom to the aircraft's power supply via line 544. Power conditioning circuit 526 converts the DC output of the fuel cell into a form required by the aircraft. It may for example consist of a static inverter for generating a conventional 120V 400Hz AC supply. Adjusting the fuel cell gas temperature allows the  
10 power output of the fuel cell to be varied in accordance with varying electrical loads, as well as allowing the power output to remain constant when engine temperature varies due to varying engine loading.

The sensors and feedback-control paths associated with automatic temperature control  
15 have been omitted from the figure for clarity as such arrangements are well known to the skilled person.

**CLAIMS:**

1. A jet engine including an integral fuel cell.
2. A jet engine as claimed in claim 1 in which the fuel cell is positioned at a combustion chamber of the engine.
3. A jet engine as claimed in claim 2 in which the fuel cell comprises a solid electrolyte membrane arranged to utilise oxygen partial pressure gradients between respective first and second faces of the membrane.
4. A jet engine as claimed in claim 3 comprising means to expose the said first face to a relatively oxygen-poor gas produced by the breaking-down of hydrocarbon fuel and means to expose the said second face to atmospheric air.
5. A jet engine as claimed in claim 4 comprising a turbine and a compressor for compressing atmospheric air, in which the means to expose the said second face to atmospheric air comprises conduit means arranged to direct air compressed by the compressor across said second face.
6. A jet engine as claimed in claim 5 in which the first face is arranged to be exposed to combustion products of fuel burnt in the combustion chamber, said relatively oxygen-poor gas consisting of the said combustion products.

7. A jet engine as claimed in claim 6 in which the first face comprises a portion of an inner wall of the combustion chamber which is directly exposed to the combustion chamber flame.
- 5 8. A jet engine as claimed in claim 5 further comprising a reformer for at least partially breaking down hydrocarbon fuel to produce a gas mixture containing hydrogen, said gas mixture comprising said relatively oxygen-free gas, and means to supply the reformer with heat generated by combustion of fuel within the engine.
- 10 9. A jet engine as claimed in claim 8 in which the reformer is arranged in a wall of the combustion chamber and the means to supply the reformer with heat comprises a heat conduction path through a wall of the combustion chamber arranged to convey heat directly from the combustion process to the reformer.
- 15 10. A jet engine as claimed in claim 8 in which the means to supply comprises means to adjust the temperature of heat supplied to the reformer.
11. A jet engine as claimed in claim 10 in which the means to adjust temperature comprises means to produce gas at a predetermined temperature, comprising means to mix hot products of the combustion process with relatively cool air from the compressor in variable proportions according to the temperature required.
- 20 12. A jet engine as claimed in claim 10, further comprising fuel pre-heater means for

pre-heating the fuel supplied to the reformer, said fuel pre-heating means being heated by said gas at a predetermined temperature

13. A jet engine as claimed in claim 11 or 12 in which the means to adjust the  
5 temperature adjusts temperature according to the electrical power output demanded of the  
fuel cell.

14. A jet engine as claimed in any one of claims 11 to 13 in which the means to adjust  
temperature adjust the temperature in response to changes in combustion products  
10 temperature.

15. A jet engine substantially as described with reference to, or shown in, figures 2  
and 3; figures 2 and 4; or figure 5 of the drawings.